IN-LINE METHOD OF MAKING HEAT-TREATED AND ANNEALED ALUMINUM ALLOY SHEET

FIELD OF THE INVENTION

The present invention relates to a method of making aluminum alloy sheet in a continuous in-line process. More specifically, a continuous process is used to make aluminum alloy sheet of T or O temper having the desired properties, with the minimum number of steps and shortest possible processing time.

BACKGROUND INFORMATION

Conventional methods of manufacturing of aluminum alloy sheet for use in commercial applications such as auto panels, reinforcements, beverage containers and aerospace applications employ batch processes which include an extensive sequence of separate steps. Typically, a large ingot is cast to a thickness of up to about 30 inches and cooled to ambient temperature, and then stored for later use. When an ingot is needed for further processing, it is first "scalped" to remove surface defects. Once the surface defects have been removed, the ingot is preheated to a temperature of about 1040°F for a period of 20 to 30 hours, to ensure that the components of the alloy are properly distributed throughout the metallurgical structure. It is then cooled to a lower temperature for hot rolling. Several passes are applied to reduce the thickness of the ingot to the required range for cold rolling. An intermediate anneal or a self-anneal is typically carried out on the coil. The resulting "hot band" is then cold-rolled to the desired gauge and coiled. For non – heat-treated products, the coil is further annealed in a batch step to obtain O-temper. To produce heat-treated products, the coiled sheet is subjected to a separate heat treatment operation, typically in a continuous heat-treat line. This involves unwinding the coil, solution heat treatment at a high temperature, quenching and recoiling. The above process, from start to finish, can take several weeks for preparing the coil for sale, resulting in large inventories of work in progress and final product, in addition to scrap losses at each stage of the process.

Because of the lengthy processing time in this flow path, numerous attempts have been made to shorten it by elimination of certain steps, while maintaining the desired properties in the finished product.

For example, U.S. Patent No. 5,655,593 describes a method of making aluminum alloy sheet where a thin strip is cast (in place of a thick ingot) which is rapidly rolled and continuously cooled for a period of less than 30 seconds to a temperature of less than 350°F. U.S. Patent No. 5,772,802 describes a method in which the aluminum alloy cast strip is quenched, rolled, annealed at temperatures between 600° and 1200°F for less than 120 seconds, followed by quenching, rolling and aging.

U.S. Patent No. 5,356,495 describes a process in which the cast strip is hot-rolled, hot-coiled and held at a hot-rolled temperature for 2-120 minutes, followed by uncoiling, quenching and cold rolling at less than 300°F, followed by recoiling the sheet.

None of the above methods disclose or suggest the sequence of steps of the present invention. There continues to be a need to provide a continuous in-line method of making heat-treated (T temper) and annealed (O temper) sheet having the desired properties in a shorter period of time, with less or no inventory and less scrap losses.

SUMMARY OF THE INVENTION

The present invention solves the above need by providing a method of manufacturing aluminum alloy sheet in a continuous in-line sequence comprising (i) providing a continuously-cast aluminum alloy strip as feedstock; (ii) optionally quenching the feedstock to the preferred hot rolling temperature; (iii) hot or warm rolling the quenched feedstock to the required thickness, (iv) annealing or solution heat-treating the feedstock in-line, depending on alloy and temper desired; and (v) optionally, quenching the feedstock. Preferably, additional steps include tension leveling and coiling.

This method allows the elimination of many steps and much processing time, and yet still results in an aluminum alloy sheet having all of the desired properties. Both heat-treated and O temper products are made in the same

production line which takes about 30 seconds to convert molten metal to finished coil. It is an object of the present invention, therefore, to provide a continuous in-line method of making aluminum alloy sheet having properties similar to or exceeding those provided with conventional methods.

It is an additional object of the present invention to provide a continuous in-line method of making aluminum alloy sheet more quickly so as to minimize waste and processing time.

It is a further object of the present invention to provide a continuous in-line method of making aluminum alloy sheet, in a more efficient and economical process.

These and other objects of the present invention will become more readily apparent from the following figures, detailed description and appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is further illustrated by the following drawings in which:

Figure 1 is a flow chart of the steps of the method of the present invention, in one embodiment;

Figure 2 is a schematic diagram of one embodiment of the apparatus used in carrying out the method of the present invention.

Figure 3 is an additional embodiment of the apparatus used in carrying out the method of the present invention. This line is equipped with four rolling mills to reach a finer finished gauge.

Figure 4a is a graph demonstrating the equi-biaxial stretching performance of 6022-T43 sheet (0.035 inch gauge) made in-line compared with sheet made from DC ingot and heat-treated off-line.

Figure 4b is a graph demonstrating the equi-biaxial stretching performance of 6022-T4 Alloy made in-line compared with sheet made from DC ingot and heat-treated off-line.

Figure 5 is a picture of Sample 804908 (Alloy 6022 in T43 temper) after e-coating.

Figure 6a is a picture demonstrating the grain size of Alloy 6022 rolled in-line to 0.035 inch gauge without pre-quench.

Figure 6b is a picture demonstrating the grain size of Alloy 6022 rolled in-line to 0.035 inch gauge.

Figure 7a depicts an as-cast structure in Alloy 6022 transverse section.

Figure 7b consists of two pictures demonstrating the surface and shell structure of Alloy 6022 in as-cast condition in transverse section.

Figure 7c is a picture of the center zone structure of Alloy 6022 in as-cast condition in transverse section.

Figure 7d consists of two pictures demonstrating pores and constituents (mainly AlFeSi particles) in the center zone of Alloy 6022 cast structure in transverse section.

Figure 8 depicts the as-cast microstructure of Al + 3.5% Mg alloy in transverse direction.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention provides a method of manufacturing aluminum alloy sheet in a continuous in-line sequence comprising: (i) providing a continuously-cast thin aluminum alloy strip as feedstock; (ii) optionally, quenching the feedstock to the preferred hot or warm rolling temperature; (iii) hot or warm rolling the quenched feedstock to the desired final thickness; (iv) annealing or solution heat-treating the feedstock in-line, depending on alloy and temper desired; and (v) optionally, quenching the feedstock, after which it is preferably tension-leveled and coiled. This method results in an aluminum alloy sheet having the desired dimensions and properties. In a preferred embodiment, the aluminum alloy sheet is coiled for later use. This sequence of steps is reflected in the flow diagram of Figure 1, which shows a continuously-cast aluminum alloy strip feedstock **1** which is optionally passed through shear and trim stations **2**, optionally quenched for temperature adjustment **4**, hot-rolled **6**, and optionally trimmed **8**. The feedstock is then either annealed **16** followed by suitable quenching **18** and optional coiling **20** to produce O temper products **22**, or solution heat treated **10**, followed by suitable quenching **12** and optional coiling **14** to produce T temper products **24**. As can be seen in Figure 1, the temperature of the heating step and the subsequent quenching step will vary depending on the desired temper.

As used herein, the term "anneal" refers to a heating process that causes recrystallization of the metal to occur, producing uniform formability and assisting in earing control. Typical temperatures used in annealing aluminum alloys range from about 600° to 900 ° F.

Also as used herein, the term "solution heat treatment" refers to a metallurgical process in which the metal is held at a high temperature so as to cause the second phase particles of the alloying elements to dissolve into solid solution. Temperatures used in solution heat treatment are generally higher than those used in annealing, and range up to about 1060°F. This condition is then maintained by quenching of the metal for the purpose of strengthening the final product by controlled precipitation (aging).

As used herein, the term "feedstock" refers to the aluminum alloy in strip form. The feedstock employed in the practice of the present invention can be prepared by any number of continuous casting techniques well known to those skilled in the art. A preferred method for making the strip is described in US 5,496,423 issued to Wyatt-Mair and Harrington. Another preferred method is as described in co-pending applications Serial Nos. 10/078,638 (now US Patent 6,672,368) and 10/377,376, both of which are assigned to the assignee of the present invention. The continuously-cast aluminum alloy strip preferably ranges from about 0.06 to 0.25 inches in thickness, more preferably about 0.08 to 0.14 inches in thickness. Typically, the cast strip will have a width up to about 90 inches, depending on desired continued processing and the end use of the sheet.

Referring now to Figure 2, there is shown schematically a preferred apparatus used in carrying out a preferred embodiment of the method of the present invention. Molten metal to be cast is held in melter holders **31**, **33** and **35**, is passed through troughing **36** and is further prepared by degassing **37** and filtering **39**. The tundish **41** supplies the molten metal to the continuous caster **45**. The metal feedstock **46** which emerges from the caster **45** is moved through optional shear **47** and trim **49** stations for edge trimming and transverse cutting, after which it is passed to a quenching station **51** for adjustment of rolling temperature. The shear station is operated when the process in interrupted; while running, shear is open.

After optional quenching **51**, the feedstock **46** is passed through a rolling mill **53**, from which it emerges at the required final thickness. The feedstock **46** is passed through a thickness gauge **54**, a shapemeter **55**, and optionally trimmed **57**, and is then annealed or solution heat-treated in a heater **59**.

Following annealing/solution heat treatment in the heater **59,** the feedstock **46** passes through a profile gauge **61**, and is optionally quenched at quenching station **63**. Additional steps include passing the feedstock **46** through a tension leveler to flatten the sheet at station **65**, and subjecting it to surface inspection at station **67**. The resulting aluminum alloy sheet is then coiled at the coiling station **69**. The overall length of the processing line from the caster to the coiler is estimated at about 250 feet. The total time of processing from molten metal to coil is therefore about 30 seconds.

Any of a variety of quenching devices may be used in the practice of the present invention. Typically, the quenching station is one in which a cooling fluid, either in liquid or gaseous form is sprayed onto the hot feedstock to rapidly reduce its temperature. Suitable cooling fluids include water, air, liquefied gases such as carbon dioxide, and the like. It is preferred that the quench be carried out quickly to reduce the temperature of the hot feedstock rapidly to prevent substantial precipitation of alloying elements from solid solution.

In general, the quench at station **51** reduces the temperature of the feedstock as it emerges from the continuous caster from a temperature of about 1000°F to the desired hot or warm rolling temperature. In general, the feedstock will exit the quench at station **51** with a temperature ranging from about 400° to 900°F, depending on alloy and temper desired. Water sprays or an air quench may be used for this purpose.

Hot or warm rolling **53** is typically carried out at temperatures within the range of about 400° to 1020°F, more preferably 700° to 1000°F. The extent of the reduction in thickness affected by the hot rolling step of the present invention is intended to reach the required finish gauge. This typically involves a reduction of about 55%, and the as-cast gauge of the strip is adjusted so as to achieve this reduction. The temperature of the sheet at the exit of the rolling station is between

about 300° and 850°F, more preferably 550° to 800°F, since the sheet is cooled by the rolls during rolling.

Preferably, the thickness of the feedstock as it emerges from the rolling station **53** will be about 0.02 to 0.15 inches, more preferably about 0.03 to 0.08 inches.

The heating carried out at the heater **59** is determined by the alloy and temper desired in the finished product. In one preferred embodiment, for T tempers, the feedstock will be solution heat-treated in-line, at temperatures above about 950°F, preferably about 980°-1000°F. Heating is carried out for a period of about 0.1 to 3 seconds, more preferably about 0.4 to 0.6 seconds.

In another preferred embodiment, when O temper is desired, the feedstock will require annealing only, which can be achieved at lower temperatures, typically about 700° to 950F°, more preferably about 800°-900F°, depending upon the alloy. Again, heating is carried out for a period of about 0.1 to 3 seconds, more preferably about 0.4 to 0.6 seconds.

Similarly, the quenching at station **63** will depend upon the temper desired in the final product. For example, feedstock which has been solution heat-treated will be quenched, preferably air and water quenched, to about 110° to 250°F, preferably to about 160°-180°F and then coiled. Preferably, the quench at station **63** is a water quench or an air quench or a combined quench in which water is applied first to bring the temperature of the sheet to just above the Leidenfrost temperature (about 550°F for many aluminum alloys) and is continued by an air quench. This method will combine the rapid cooling advantage of water quench with the low stress quench of air jets that will provide a high quality surface in the product and will minimize distortion. For heat treated products, an exit temperature of 200°F or below is preferred.

Products that have been annealed rather than heat-treated will be quenched, preferably air- and water-quenched, to about 110° to 720°F, preferably to about 680° to 700°F for some products and to lower temperatures around 200°F for other products that are subject to precipitation of intermetallic compounds during cooling, and then coiled.

Although the process of the invention described thus far in one embodiment having a single step hot or warm rolling to reach the required final gauge, other embodiments are contemplated, and any combination of hot and cold rolling may be used to reach thinner gauges, for example gauges of about 0.007-0.075 inches. The rolling mill arrangement for thin gauges could comprise a hot rolling step, followed by hot and/ or cold rolling steps as needed. In such an arrangement, the anneal and solution heat treatment station is to be placed after the final gauge is reached, followed by the quench station. Additional in-line anneal steps and quenches may be placed between rolling steps for intermediate anneal and for keeping solute in solution, as needed. The pre-quench before hot rolling needs to be included in any such arrangements for adjustment of the strip temperature for grain size control. The pre-quench step is a pre-requisite for alloys subject to hot shortness.

Figure 3 shows schematically an apparatus for one of many alternative embodiments in which additional heating and rolling steps are carried out. Metal is heated in a furnace **80** and the molten metal is held in melter holders **81**, **82**. The molten metal is passed through troughing **84** and is further prepared by degassing **86** and filtering **88.** The tundish **90** supplies the molten metal to the continuous caster **92**, exemplified as a belt caster, although not limited to this. The metal feedstock **94** which emerges from the caster **92** is moved through optional shear **96** and trim **98** stations for edge trimming and transverse cutting, after which it is passed to an optional quenching station **100** for adjustment of rolling temperature.

After quenching **100**, the feedstock **94** is passed through a hot rolling mill **102**, from which it emerges at an intermediate thickness. The feedstock **94** is then subjected to additional hot milling **104** and cold milling **106**, **108** to reach the desired final gauge.

The feedstock **94** is then optionally trimmed **110** and then annealed or solution heat-treated in heater **112**. Following annealing/solution heat treatment in the heater **112**, the feedstock **94** optionally passes through a profile gauge **113**, and is optionally quenched at quenching station **114**. The resulting sheet is subjected to x-ray **116**, **118** and surface inspection **120** and then optionally coiled.

Suitable aluminum alloys for heat-treatable alloys include, but are not limited to, those of the 2XXX, 6XXX and 7XXX Series. Suitable non – heat-

treatable alloys include, but are not limited to, those of the 1XXX, 3XXX and 5XXX Series. The present invention is applicable also to new and non-conventional alloys as it has a wide operating window both with respect to casting, rolling and in-line processing.

EXAMPLES

The following examples are intended to illustrate the invention and should not be construed as limiting the invention in any way.

Example 1: In-line fabrication of a heat-treatable alloy. A heat-treatable aluminum alloy was processed in-line by the method of the present invention. The composition of the cast was selected from the range of 6022 Alloy that is used for auto panels. The analysis of the melt was as follows:

Element	Percentage by weight
Si	0.8
Fe	0.1
Cu	0.1
Mn	0.1
Mg	0.7

The alloy was cast to a thickness of 0.085 inch at 250 feet per minute speed and was processed in line by hot rolling in one step to a finish gauge of 0.035 inches, followed by heating to a temperature of 980°F for 1 second for solution heat treatment after which it was quenched to 160°F by means of water sprays and was coiled. Samples were then removed from the outermost wraps of the coil for evaluation. One set of samples was allowed to stabilize at room temperature for 4 – 10 days to reach T4 temper. A second set was subjected to a special pre-aging treatment at 180°F for 8 hours before it was stabilized. This special temper is called T43. The performance of the samples was evaluated by several tests that included response to hemming, uniaxial tension, equi-biaxial stretching (hydraulic bulge) and aging in an auto paint-bake cycle. The results obtained were compared with those obtained on sheet of the same alloy made by the conventional ingot method. Deformed samples from the hydraulic bulge test were also subjected to a simulated auto painting cycle to check for surface quality and response to painting. In all respects, the sheet fabricated

in-line by the present method performed as well as or better than that from the ingot method.

Table 1: Tensile properties of 6022-T43 sheet fabricated in line by the present method. Measurements were made after nine days of natural aging on ASTM specimens. Cast number: 031009.

pre-roll quench	TFX F	in line quench, F	ATC S number	TYS ksi	UTS ksi	Elongation, % uniform	Elongation, % total	r value	r bar
					T43 (longitudinal)				
off	980	114	805656	18.6	36.6	25.5	30.4	1.079	
off	1000	114	805658	19.3	37.2	23.6	26.7	1.144	
Sheet from conventional ingot - T43			typical	17.8	34.5	21.5	24.5	0.826	
					T43 (45^0)				
off	980	114	805656	18.5	36.4	24.2	28.0	0.760	
off	1000	114	805658	19.6	37.6	25.4	29.7	0.725	
Sheet from conventional ingot - T43			typical	17.0	33.4	24.5	26.9	0.602	
					T43 (transverse)				
off	980	114	805656	18.4	36.2	22.1	24.5	0.988	0.897
off	1000	114	805658	19.0	36.7	23.6	26.3	0.889	0.896
Sheet from conventional ingot - T43			typical	16.6	32.5	22.8	26.4	0.642	0.668
Customer requirements (min)				14.0		19.0	21.0		0.500

Notes: 1. T43 temper was obtained by holding samples at 180 F for 8 hours in a separate furnace after fabrication The time between fabrication and entry of samples into furnace was less than 10 minutes.

Results of the tensile testing are shown in Table 1 for T43 temper sheet in comparison with those typical for sheet made from ingot. It is noted that in all respects, the properties of the sheet made by the present method exceeded the customer requirements and compared very well with those for conventional sheet in the same temper. With respect to the isotropy of the properties as measured by the r values, for example, the sheet of the present method obtained 0.897 compared to 0.668 for ingot. In these tests, a generally higher strain hardening coefficient of 0.27 (compared to 0.23 for ingot) was also found. Both of these two findings are important because they suggest that the sheet of the present method is more isotropic and better able to resist thinning during forming operations. Similar observations applied also to T4 temper sheet samples.

Flat hemming tests were done after 28 days of room temperature aging. In these tests, a pre-stretch of 11% was applied compared to 7% required in customer specifications. Even under these more severe conditions, all samples obtained an

acceptable rating of 2 or 1, Table 2. In similar testing, sheet made from ingot shows an average of 2-3 in the longitudinal hems and 2 in transverse hems. This suggests that the sheet fabricated in-line has superior hemmability. Some samples were solution heat-treated off-line in a salt bath after fabrication. When tested, these samples, too, showed excellent hemming performance as seen in Table 2.

Table 2 : Flat hem rating (at 11 % pre-stretch) after 28 days' of natural aging for alloy 6022 at 0.035 inch gauge (cast number: 030820)

pre-roll quench	in-line anneal, F	in line quench, F	gauge inches	ATC S number	hem rating L	hem rating T	comments
				C710 - T43 temper			
off	950	160	0.035	804908	2	2	fabricated in line
off	950	160	0.035	804909	2	2	fabricated in line
on	off	104	0.035	804912	1	2	off-line heat treat: 1040 F/1 min.
on	920	140	0.035	804914	2	2	off-line heat treat: 1010 F/1 min.
Conventional ingot sheet - T43 temper					"2-3"	2	

Notes: 1. T43 temper was obtained by holding samples at 180 F for 8 hours in a separate furnace after fabrication The time between fabrication and entry of samples into furnace was less than 10 minutes.
2. Requirement for hemming: A rating of 2 or less at 7% pre-stretch.

In equi-biaxial stretching by hydraulic bulge, the performance of the sheet made in line was comparable to those of sheet made from ingot as seen in stress strain curves in Figures 4a and 4b. This observation applied both in T4 and in T43 temper. The performance in this test was particularly important because it is known that continuous-cast materials typically do not perform well in this test due to the presence of center line segregation of coarse intermetallic particles.

Response to paint-bake cycle was evaluated by holding the samples in an oven at 338°F for a duration of 20 minutes (Nissan cycle). The tensile yield strength of the samples increased by up to 13 ksi by this treatment, Table 3. In all cases, the required minimum of 27.5 ksi was met easily in the T43 temper. The overall response in this temper was comparable to the average performance of sheet made from DC ingot. As expected, the T4 temper samples were somewhat unsatisfactory in this respect.

Table 3: Paint bake response of alloy C710 produced in Reno at rolled gauge of 0.035 inches. Cast number: 030820. Nissan/Toyota paint bake cycle: 2% stretch, 338 F / 20 minutes. TYS required: 27.5 ksi min.

pre-roll quench	TFX F	in line quench, F	Temper	Date SHT	Date Test	Natural Age Days	Sample ID	TYS ksi	UTS ksi	Elong %	ΔYS ksi
			T4	20-Aug	27-Aug	7	804866-T	16.9	33.8	23.2	
off	950	160	T4+PB	in line		7	804866-T	25.8	37.7	20.8	8.9
			T4	20-Aug	27-Aug	7	804867-T	16.8	34.0	23.0	
off	950	160	T4+PB	in line		7	804867-T	26.0	37.8	20.2	9.2
			T43	20-Aug	27-Aug	7	804908-T	16.8	33.8	22.0	
off	950	160	T43+PB	in line		7	804908-T	27.6	39.0	19.5	10.8
			T43	20-Aug	27-Aug	7	804909-T	16.6	33.8	25.0	
off	950	160	T43+PB	in line		7	804909-T	29.6	40.5	19.5	13.0
			T43	21-Aug	27-Aug	6	804912-T	18.4	35.2	24.2	
on	off	104	T43+PB	1040/1min		6	804912-T	28.9	40.5	23.8	10.5
			T43	22-Aug	27-Aug	5	804914-T	18.6	35.2	25.0	
on	920	140	T43+PB	1010/1min		5	804914-T	30.1	41.1	22.5	11.5
				DC ingot	T43	7		17.1	33.3	26.3	
				typical	T43+PB	7	JIS tests	30.5	40.9	26.4	13.4

Notes: 1. Samples were held at 180 F for 8 hours for the T43 temper (quench aged).
2. Samples 804912 and 804914: Laboratory solution heat treat was carried out in a salt bath under conditions indicated followed by water quenching.

The deformed hydraulic bulge specimens were inspected for surface quality and were found to show no undesirable features such as orange peel, blisters, etc. Selected bulge samples were subjected to a simulated auto-paint cycle. Figure 5 shows excellent painted surface quality with no paint brush lines, blisters or linear features.

Sheet at finished gauge was examined for grain size and was found to have a mean grain size of 27 μm in the longitudinal and 36 μm in the thickness direction, Figure 6. This is substantially finer than that of 50 – 55 μm typical for sheet made from ingot. Since a fine grain size is recognized to be generally beneficial, it is likely that a part of the good/superior properties of the sheet made by the present method was due to this factor. It was found that even finer grain size could be obtained in the present method by rapidly cooling the strip to about 700°F before it is rolled. This effect is illustrated in Figures 6a and 6b where the two samples are shown side by side. The grain size of the cooled sample (6b) was 20 μm in longitudinal and 27 μm in transverse direction, which are 7 and 9 μm, respectively, finer than those observed in the sheet which had no pre-quench cooling (6a).

Samples of as-cast strip were quenched and examined metallographically to further understand the benefits of thin strip casting. The samples showed the three-layered structure characteristic of the Alcoa strip casting process, Figure 7a.

The surfaces of the strip were clean (no liquation, blisters or other surface defects) with a fine microstructure, Figure 7b. Unlike the material continuously cast by Hazelett belt casters or roll casters, the strip of the present method showed no centerline segregation of coarse intermetallic compounds. On the contrary, the last liquid to solidify had formed fine second phase particles between grains in a center zone that covered about 25% of the section, Figure 7c. This absence of a marked centerline segregation in the present method provided the good mechanical properties observed, especially in the equi-biaxial stretch tests. Most of the second phase particles observed were AlFeSi phase with an average size < 1 μm, Figure 7d. Some Mg_2Si particles were seen in the center zone of the sample, but none was noted in the outer "shells", Figure 7b. This suggested that the rapid solidification in the caster was able to keep the solute in solution in the outer zones of the structure. This factor, combined with the fine overall microstructure of the strip (see Table 4), enabled the complete dissolution of all solute at substantially lower solution heat treatment temperatures of 950° – 980°F than 1060°F that would be needed for sheet prepared from DC ingot.

Table 4 : Characteristics of constituent particles and pores found in as -cast samples of alloy C710 (cast number: 030820)

location in strip	pores av. diam. μm	pores area %	constituents av. diam. μm	constituents area %
center, transverse	0.37	0.37	0.50	0.143
center, longitudinal	0.38	0.34	0.31	0.077
average	*0.38*	*0.36*	*0.41*	*0.11*
shell, transverse	0.35	0.21	0.32	0.23
shell, longitudinal	0.33	0.25	0.28	0.19
average	*0.34*	*0.23*	*0.30*	*0.21*

Notes: 1. The constituents were mainly AlFeSi phase. Small amount of Mg_2Si was also seen in center zone.
2. Each result is average 20 different frames.

Example 2: In-line fabrication of a non-heat treatable alloy. A non – heat-treatable aluminum alloy was processed by the method of the present invention. The composition of the cast was selected from the range of the 5754 Alloy that is used for auto inner panels and reinforcements. The analysis of the melt was as follows:

Element	Percentage by weight
Si	0.2
Fe	0.2
Cu	0.1
Mn	0.2
Mg	3.5

The alloy was cast to a strip thickness of 0.085 inch at 250 feet per minute speed. The strip was first cooled to about 700°F by water sprays placed before the rolling mill, after which it was immediately processed in-line by hot rolling in one step to a finish gauge of 0.040 inches, followed by heating to a temperature of 900°F for 1 second for recrystallization anneal after which it was quenched to 190°F by means of water sprays and was coiled. The performance of the samples was evaluated by uniaxial tensile tests and by limiting dome height (LDH).

Results of the tensile testing are shown in Table 5. The TYS and elongation of the sample in the longitudinal direction were 15.2 ksi and 25.7%, respectively, well above the minimum of 12 ksi and 17% required for Alloy 5754. UTS value was 35.1 ksi, in the middle of the range specified as 29-39 ksi. In the limiting dome height test, a value of 0.952 inch was measured that met the required minimum of 0.92 inch. These values compared well with typical properties reported for sheet prepared from DC ingot. Sheet of the present invention had a higher elongation, higher UTS and higher strain hardening coefficient n. A higher anisotropy value r was expected, but was not verified in the testing of this sample. The r value was 0.864 compared to 0.92 for DC sheet.

Sheet at finished gauge was examined for grain size and was found to have a mean grain size of 11-14 μm (ASTM 9.5). This is substantially finer than that of 16 μm typical for sheet made from ingot. Since a fine grain size is recognized to be generally beneficial, it is likely that a part of the good/superior properties of the sheet made by the present method was due to this factor.

Samples of as-cast strip were quenched and examined metallographically. Despite differences in chemical composition, the as-cast samples showed the same three-layered structure as that described above for Alloy 6022, Figure 8. This confirms that the three-layered fine microstructure that enables in-line processing of the strip described in this invention, is a characteristic of the Alcoa strip casting process.

Variations of the fabrication path were also investigated. In one test, 0.049 inch gauge sheet was fabricated in-line without the in-line anneal, Table 5. The sample was then flash-annealed off-line in a salt bath at 975°F for 15 s followed by water quenching. That sample showed similar properties and a high r value comparable to those described above for sheet fabricated with in-line anneal. This equivalence conformed that in-line fabrication is able to develop the full properties of the alloy in O-temper. In another test, the strip was hot rolled in-line to 0.049 inch gauge and was quenched to 160°F with no in-line anneal. It was then cold-rolled to 0.035 inch gauge and was flash-annealed at 950°F for 15 seconds, Table 5. That sheet, too, developed good mechanical properties. These observations suggested that hot and cold rolling could be combined with an-in line final anneal to make sheet of a wide range of thickness of O-temper products by the present invention.

Table 5: Uniaxial tensile test results for Al-3.5 % Mg AX alloy processed in line by the present invention.

S number	Reno cast #	alloy	test gauge, inch	hot roll gauge, inch	flow path: pre-roll quench	flow path: anneal,F	flow path: quench, F	L 45 T	TYS ksi	UTS ksi	elongation, % uniform	elongation, % total	r value	r bar	n value
805314	030902B	Al-3.5% Mg	0.033	0.049	on	off	on	L	16.5	36.2	17.9	22.3	0.781		0.309
								45	16.8	35.3	24.1	28.8	1.120	0.947	0.311
								T	16.1	35.6	21.3	22.2	0.766		0.306
805035	030902B	Al-3.5% Mg	0.049	0.049	on	off	on	L	15.6	35.9	19.2	20.8	0.835		0.314
								45	15.4	35.5	21.7	22.5	1.200	1.05	0.303
								T	15.8	35.8	22.4	26.9	0.963		0.317
805747	31021	Al-3.5% Mg	0.040	0.040	on	900	190	L	15.2	35.1	23.2	25.7	0.778		0.323
								45	14.6	34.8	23.1	25.3	0.938	0.864	0.326
								T	14.6	34.7	23.2	24.5	0.802		0.322
Alloy 5754 for comparison															
	DC ingot	5754	0.036					L	14.6	29.7	20.4	22.2	0.978		0.301
								45	14.4	28.9	21.2	22.0	0.809	0.92	0.303
								T	14.6	28.9	19.7	22.4	1.082		0.305

Notes: 1. AA registered requirements for 5754: TYS=12 ksi min. (L), UTS= 29-39 ksi (L), Elongation: 17 % min (L)., LDH = 0.92 inches min.
2. Samples 805314 and 805035 were annelaed off-line in a salt bath at 950 Fand 975 F, respectively, for 15 seconds following which they were quenched in water.

Example 3: In-line fabrication of a non – heat-treatable ultra high Mg alloy. An Al -10% Mg alloy was processed by the method of the present invention. The composition of the melt was as follows:

Element	Percentage by weight
Si	0.2
Fe	0.2
Cu	0.2
Mn	0.3
Mg	9.5

The alloy was cast to a strip thickness of 0.083 inch at 230 feet per minute speed. The strip was first cooled to about 650°F by water sprays placed before the rolling mill. It was then immediately hot-rolled in-line in one step to a finish gauge of 0.035 inch followed by an anneal at 860°F for 1 second for recrystallization and spray quenching to 190°F. The sheet was then coiled. Performance of the sheet in O-temper was evaluated by uniaxial tensile tests on ASTM – 4 d samples removed from the last wraps of the coil. In the longitudinal direction, the samples showed TYS and UTS values of 32.4 and 58.7 ksi, respectively. These very high strength levels, higher by about 30% than those reported for similar alloys, were accompanied by high elongation: 32.5% total elongation and 26.6% uniform elongation. The samples showed very fine grain structure of ~ 10 μm size.

Example 4: In-line fabrication of a recyclable auto sheet alloy. An Al –1.4% Mg alloy was processed by the method of the present invention. The composition of the melt was as follows:

Element	Percentage by weight
Si	0.2
Fe	0.2
Cu	0.2
Mn	0.2
Mg	1.4

The alloy was cast to a strip thickness of 0.086 inch at 240 feet per minute speed. It was rolled to 0.04 inch gauge in one step, flash annealed at 950 F, following which it was water quenched and coiled. The quenching of the rolled sheet was done in two different ways to obtain O temper and T temper by different settings of the post quench **63.** For the T temper, the strip was pre-quenched by quench **53** to about 700 F before warm-rolling to gauge and was post-quenched to 170 F (sample #:804995 in Table 6). In a second case, the sheet was post quenched to around 700 F and was warm coiled to create O temper. The O-temper coil was done both by warm rolling (sample: 804997) and by hot rolling (sample: 804999).

Performance of the sheet was evaluated by uniaxial tensile tests on ASTM – 4 d samples and by hydraulic bulge test. In the T temper, the sheet showed tensile yield strength, ultimate tensile strength and elongation values well above the requirements for alloy 5754 in O-temper and as good as those available in sheet made by the conventional ingot method, Table 6. In the hydraulic bulge test, too, the performance of the T temper AX-07 was very close to that of alloy 5754, Figure 8. This suggests that AX-07 in T temper made by the method of the present invention can be used to replace the 5754 sheet in inner body parts and reinforcements in auto applications. Such a replacement would have the advantage of making those parts recyclable into the 6xxx series alloys, by virtue of the lower Mg content, used in outer skin parts of autos without the need for separation.

Samples were also tested in O-temper made by the present method. In that temper, the strength levels were lower, around 8.8 ksi yield strength and 23 ksi tensile strength. The performance in the hydraulic bulge test improved equaling that of conventional 5754 as may be seen in Figure 8. This temper thus offers a material that would be formed more easily at lower press loads.

Whereas particular embodiments of this invention have been described above for purposes of illustration, it will be evident to those skilled in the art that numerous variations of the details of the present invention may be made without departing from the invention as defined in the appending claims.